

Influence of measure-density on combustor characteristics

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Abstract: The apparatus of scan measurement was used to gather the temperature pattern at the combustor outlet, where the average working temperature of gas was about 1700 K and the maximum temperature was about 1950 K. Consequently, the measurement part was cooled by water or air. Usually, for intermittent measurement devices, the interval of circle angel could be changed to get a high-density temperature distribution. A continuous measurement manner was adopted to get point in circle. The angle between two measure-points was 1.286° . The annular combustor outlet was about 40 to 50 mm in height, where 5 or 6 measure points were usually arranged. In this device, 10 measure points were arranged in a range of 45.5 mm. Four thermocouples were arranged in circle to obtain 2800 measure-points of the temperature field in a single experiment. Data were drawn from the whole datasheet at intervals. Each group of data whose number decreased in turn, included temperature points of 2800, 1400, 700, and 350, respectively. Several groups of temperature distributions with different densities were established. Subsequently, data processing was conducted to calculate the main combustor characteristics, including arithmetic or integral average temperature, OTDF (overall temperature distribution factor) and RTDF (radial temperature distribution factor). It is found that the data from different groups with different measuring densities result in significant difference on the combustor characteristics. The veracity of temperature characteristics increases with the growing measure-density.

Key words: combustor; temperature field; sampling density; measurement; experimental setup

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Nomenclature

t_{3a}	Combustor average inlet-air temperature($^\circ\text{C}$)	$t_{4\text{max}}$	Maximum average temperature in radius($^\circ\text{C}$)
t_{4a}	Exit arithmetic average temperature($^\circ\text{C}$)	r	Radius
t_{4i}	Temperature of i point($^\circ\text{C}$)	N	Number of field
$t_{4\text{max}}$	Maximum temperature in the field($^\circ\text{C}$)		

As the main characteristics of combustor, the temperature distributions at the combustor outlet can directly affect the reliability and life of turbine guide vane.

In order to get real temperature pattern, it is important to acquire high-density measurement points. There are two manners to improve the density of measurement points at the combustor outlet. One is to improve the density of

measurement points in circle, the other is in radius.

Experimental measurements of the combustor temperature field are of paramount importance in the design of aero-engine. The performance of temperature field can not only directly reflect the working state in the combustor, but also help deciding the effects of high-temperature gas on the turbo components^[1-5].

Besides the exit mean temperature, the combustor performance is also rated by other exit temperature pattern factors, such as OTDF, RTDF, and combustion efficiency. The veracity of original data, mainly determined by the sampling density of the temperature field, is used to decide whether the parameters can actually reflect the temperature field. The higher the density is, the closer to reality the results are. However, a higher sampling density will lead to a rapid increase on the experimental expense. Consequently, it is very important to confirm the optimum sampling density which remains unclear. In engineering, the density is empirically arranged as 1 to 4 cm²/point (Table 1).

Table 1 Sampling densities in different combustor configurations

No.	Name	Point number	Measure-density/ (cm ² /point)	Year
1	NASACR-72453	600	4.17	1969
2	WJ-6	240	2.18	1979
3	JT8	720	2.2	1980
4	A60614	600	1.875	1985
5	24E80	720	0.562	1987
6	A60631	2800	0.35	1998

As a research topic, the sampling density was not high enough, and the results had some localization. This test was to find a high-density temperature field through a precision measure device. The data were treated in statistics to obtain the optimum sampling density.

1 Method of simulation

1.1 Experimental setup

The device measurement part, used to measure the combustor outlet temperatures, consists of body and measurement system. The body comprises external-cover, inside/outside supports, drum, traversing equipment, thermocouple, and connecting part, as shown in Fig. 1. In present aero-engine, the mean temperature at the

combustor outlet can reach 1700 to 1900 K^[6-8]. The device, adopting mixed cooling manner of air and water, required 100 t water in an hour and was covered with heat-resistant coat at the gas interface.

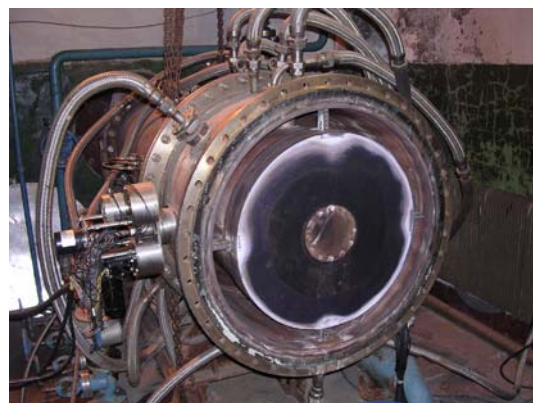


Fig. 1 Measurement section

The traversing device adopted the gearing and bearing. The direct current electromotor was used to slow down the speed. The scale of whirly angle, measured by sensors, was from 90° to 180°. The data are recorded continuously or discontinuously. Spacing angles are from 1.5° to 6° with discontinuous record, for continuously rotate, data are recorded at smaller angle. Data in this test were obtained in the continuous mode.

Measurement system completes adopting data and controlling sampling angle. The temperature readings recorded by thermocouples were transferred to NEFF 470 data acquisition system in computer by IEEE 488. The angles of sampling points were measured by angle sensor.

The temperature readings were obtained by aspirated platinum-rhodium thermocouples. The measure point was surrounded by corundum protector. The scale of measurement was from 0 to 1800 °C.

1.2 Measurement

In order to achieve high-density temperature readings^[9-11], firstly, continuous scan is adopted, which can acquire smaller angle. The minimum spacing angle was 1.286° in this test. Secondly, the spacing points in radius were very small, namely 10 points in radius. 4 5-point

thermocouples were divided into two groups, and the coordinate of two-group was arranged by interlaced. Consequently, a total of 2800 readings in an area of 976 cm^2 were taken for each measurement with the traversing thermocouple at the annular combustor outlet. The sampling density was one point reading per 0.35 cm^2 [12-15].

The temperature accuracy is 0.4% according to accuracy of themalcouple, and the angle accuracy is 0.1% .

1.3 Computing formula

The formulas of combustor performance were as follows:

Exit arithmetic average temperature

$$t_{4a} = \frac{1}{N} \sum_{i=1}^N t_{4i} \quad (1)$$

Overall temperature distribution factor

$$F_{\text{otd}} = \frac{t_{4\text{max}} - t_{4a}}{t_{4a} - t_{3a}} \quad (2)$$

Radial temperature distribution factor

$$F_{\text{rtd}} = \frac{t_{4\text{max}} - t_{4a}}{t_{4a} - t_{3a}} \quad (3)$$

2 Results and discussions

In this section, the effect of the sampling density on the average temperature and pattern factors was investigated in detail. The experimental data, recorded by 140 positions in circle, were classified in several possible combinations that would represent different measure schemes. For example, the data were divided into two/four/eight groups each of which included 1400/700/350 temperature value points, respectively. The combinations are listed in Table 2. Table 3 to Table 5 demonstrate the data from three different combustor configurations. The quadratic regression was made to obtain the relation between point number and absolute error, as shown in Fig. 2 to Fig. 13. The absolute errors of maximum temperature t_{max} , average temperature t_{ave} , OTDF and RTDF all decreases with the measurement number increasing. It should be noted that the result is close to real value with the sampling points increasing.

Table 2 Assumed temperature field measure combinations

Positions in circle	Each turn angle/ (°)	Point number	Measure-density/ (cm^2/point)	Group
35	10.286	350	2.79	8
70	5.143	700	1.39	4
140	2.571	1400	0.70	2
280	1.286	2800	0.35	1

Table 3 Results of the first combustor

Point number	t_{max} error/%	F_{otd} error/%	t_{ave} error/%	F_{rtd} error/%
2800	0	0	0	0
1400	0.2	1.1	0	1.3
700	2.7	17.1	0.2	8.5
350	5.5	43.5	0.6	10.2

Table 4 Results of the second combustor

Point number	t_{max} error/%	F_{otd} error/%	t_{ave} error/%	F_{rtd} error/%
2800	0	0	0	0
1400	0.2	1.4	0	1.1
700	3.4	20.3	0.3	10.4
350	6.1	46.8	0.7	12.3

Table 5 Results of the third combustor

Point number	t_{max} error/%	F_{otd} error/%	t_{ave} error/%	F_{rtd} error/%
2800	0	0	0	0
1400	0.8	4.2	0.1	0
700	2.7	18	0.3	5.8
350	6.1	46.6	0.7	10.6

In the figures, the marked cross point indicates a certain relation between the absolute error and point number, which illustrates that there is an appropriate number of sampling points according to the permit error. For example, Fig. 2 shows that 950 sampling points are required to make the error of the maximum temperature less than 2% . To achieve more exact result, the reading number should be calculated

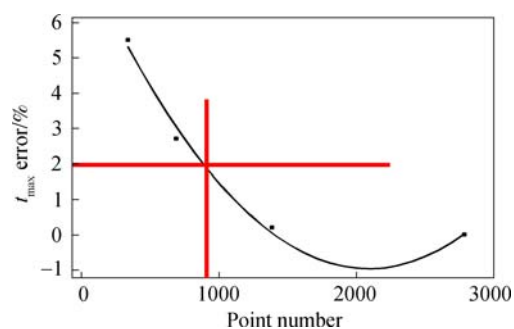


Fig. 2 Data regression of the first combustor
($t_{\max}$ error and point number)

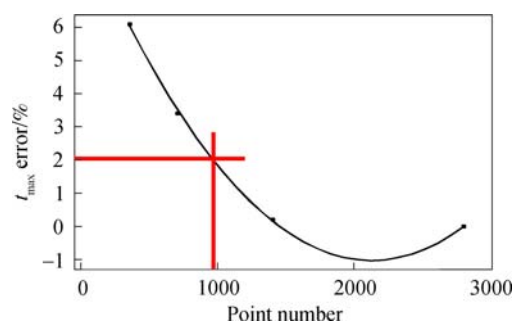


Fig. 6 Data regression of the second combustor
($t_{\max}$ error and point number)

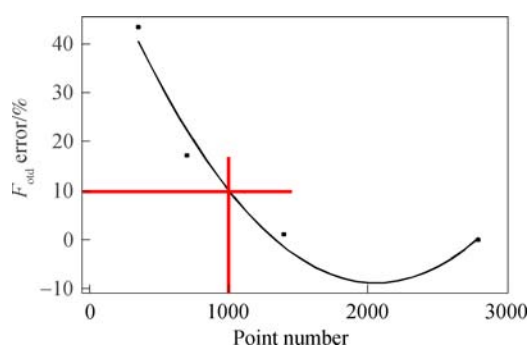


Fig. 3 Data regression of the first combustor
(F_{oid} error and point number)

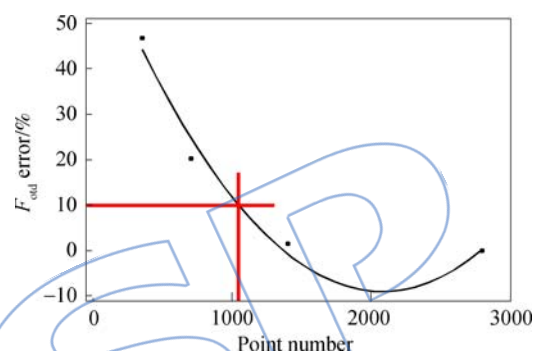


Fig. 7 Data regression of the second combustor
(F_{oid} error and point number)

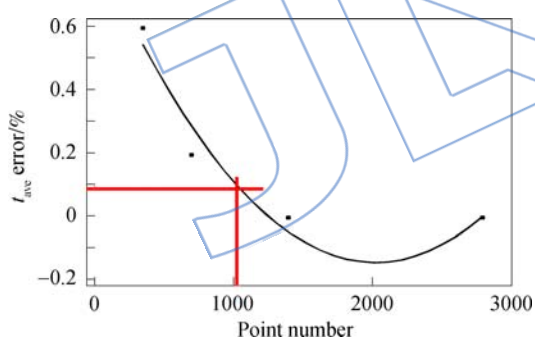


Fig. 4 Data regression of the first combustor
(t_{ave} error and point number)

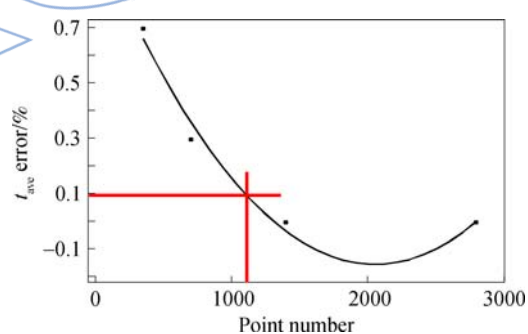


Fig. 8 Data regression of the second combustor
(t_{ave} error and point number)

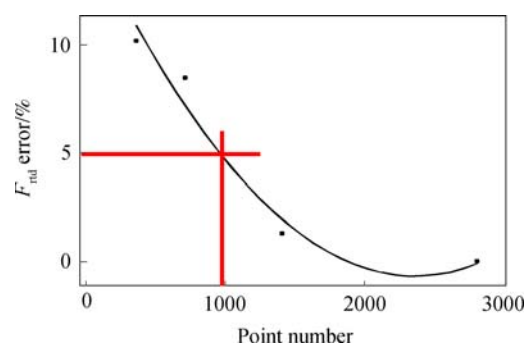


Fig. 5 Data regression of the first combustor
(F_{rtd} error and point number)

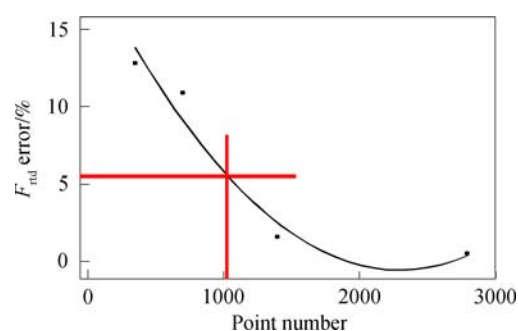


Fig. 9 Data regression of the second combustor
(F_{rtd} error and point number)

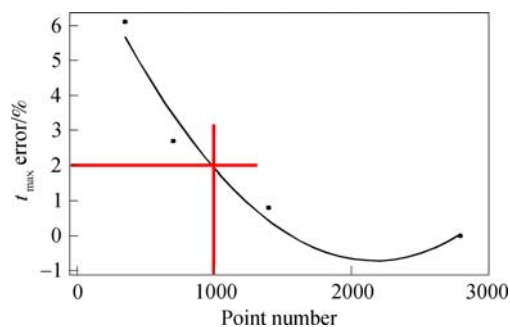


Fig. 10 Data regression of the third combustor ($t_{\max}$ error and point number)

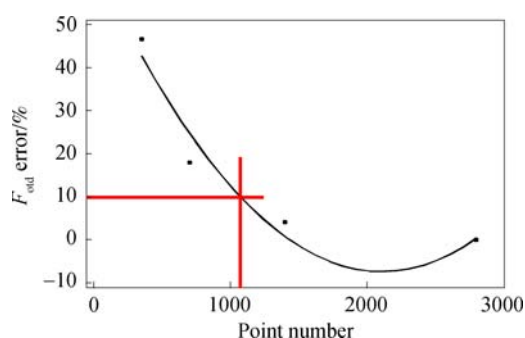


Fig. 11 Data regression of the third combustor (F_{01d} error and point number)

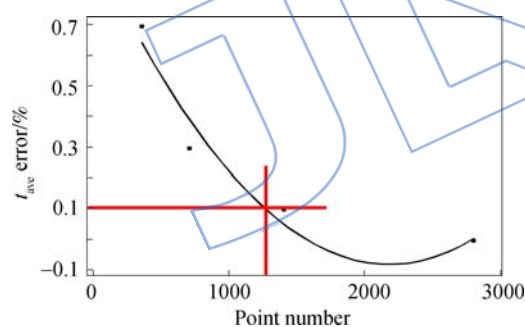


Fig. 12 Data regression of the third combustor (t_{ave} error and point number)

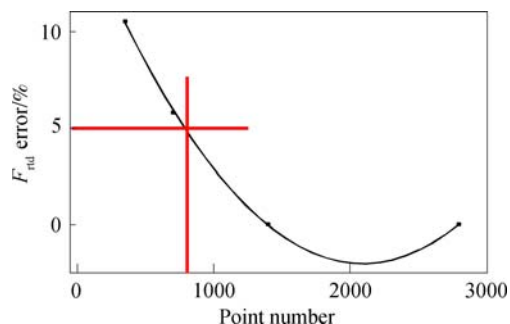


Fig. 13 Data regression of the third combustor (F_{01d} error and point number)

by the regression equation above the figures.

Generally speaking, it cannot be expected to yield average temperatures or pattern factor in high accuracy by using a low number of temperature sampling points. Consequently, it is necessary to determine the minimum number of sampling points which can provide sufficiently accurate temperatures and pattern factor. The true pattern factor is dependent upon the locating and measuring of the maximum local temperature occurring anywhere in the exhaust. When the number of sampling points is approximately 1000 (or one point per 0.89 cm^2), the absolute error of the maximum temperature, OTDF, average temperature, and RTDF will be less than 2%, 10%, 0.1%, and 5%, respectively, which may be in acceptable accuracy. An optimal sampling point should be calculated according to the figures or equations to satisfy a more exact demand. Furthermore, higher sampling density should be arranged to determine the pattern factor in reasonable accuracy.

3 Conclusions

In this paper, the influence of the measure-density on the combustor characteristics was experimentally investigated by analyzing the temperature measurements at three different combustor outlets. It is concluded that a great number of temperature sampling points, 1000 as a minimum (or one point per 0.89 cm^2), are required to ensure the absolute error of pattern factor to be less than 10%. Although the results obtained from one size of combustor may be different with those from other combustors, the conclusion in this paper can be used as an instructional rule to other combustors.

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